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Method for Operating an Internal Combustion Engine and an Internal Combustion Engine for putting the Method into Practice.

A supercharger (20) producing a continuous pressure and which discharges into an accumulator [or storage chamber] (28) is used to charge the combustion chambers (10) of a piston type internal combustion engine provided with an inlet valve (14) and an outlet valve (16). Dependent upon the ignition frequency of the allocated combustion chambers (10), an air control valve (34) disposed between the accumulator (28) and an inlet duct (36) leading to the inlet valve (14) of these combustion chambers (10) opens and closes. The phasing of said air control valve with respect to the inlet valve (14) can be adjusted between a position concentrating the supply of air from the accumulator (28) on the start of inlet and a position concentrating this supply of air on the end of inlet of these combustion chambers (10) dependent upon the desired engine operating mode, a line (40) supplying each combustion chamber with uncompressed charge being blocked when there is high pressure on the side of the combustion chamber (10) to be supplied.

Description

The invention relates to a method for operating a piston type internal combustion engine, in particular a reciprocating piston engine, with which each combustion chamber is connected to an inlet duct by at least one inlet valve controlled dependent upon the piston movement, with a supercharger discharging into an accumulator and producing a continuous pressure, and an air control valve disposed between the accumulator and each inlet duct which opens and closes with the ignition frequency of the allocated combustion chambers, the phasing of the opening center of the air control valve being displaceable from phase balance with the opening center of the respectively opening inlet valve in front of its opening center, and an internal combustion engine for putting the method into practice.

With the development of motor vehicle engines, in particular passenger car engines, essentially four development targets are set nowadays, namely high power in order to achieve high speeds, high quality performance with low numbers of revolutions, in particular high torque and spontaneous response, environmental friendliness with regard to fuel consumption, exhaust gas emissions and noise, and low costs.

In some cases these targets are mutually supporting, for example by reducing vehicle resistance and weight, not only is the maximum speed increased, but also fuel consumption and exhaust gas emissions are reduced. On the other hand, exhaust gas catalytic converters increase fuel consumption and reduce engine spontaneity and the maximum power.

Of particular significance are the measures taken to reduce vehicle weight and air resistance of vehicles, because in this way the pressure on construction volume and weight of the engines is reduced. In addition, due to the ever greater competition, there is great deal of pressure on costs.

The solution to the problems indicated above is more and more sought in the charging of internal combustion engines, in particular in exhaust gas turbocharging. Due to the conflict in interest of the development aims and due to the different operational characteristics of charging devices and internal combustion engines, only partially optimized solutions are produced. For

example, by using the exhaust gas turbocharger, the requirement for low engine weight and small constructional space is generally fulfilled, as is the requirement for high power and maximum speed. The potential for possible improvements in exhaust gas emissions and fuel consumption is not fulfilled here, and high quality performance with low numbers of revolutions is sacrificed. The torque at low numbers of revolutions is then too low, and the engine only responds to load changes with a clear delay.

The development of the turbocharger seeks to combat the low torque with low numbers of revolutions and the delayed response in that superchargers are used which achieve their optimal operating point at low numbers of revolutions, and this leads to an excess supply of supercharger energy at higher numbers of revolutions. This energy is released into the open through so-called blow off valves in the form of accumulated exhaust gases or excess charge air. The exhaust gas turbocharger only supplies the engine with an appropriate quantity of air in a narrow operational range, whereas with lower numbers of revolutions there is a lack of air because insufficient supercharger energy is available, and with higher numbers of revolutions there is an excess of energy which remains unused. As the load is increased, there is also a lack of supercharger energy.

The disadvantage of all charging devices produced in appreciable numbers is that they work according to the so-called charging principle. Here, a pressure constant air-mass flow is produced and conveyed to the engine. When the inlet valve of an engine cylinder is opened, the air flows with almost constant pressure into the cylinder and presses the cylinder downwards. In so doing, activity is produced on the piston by the air which was previously supplied in the supercharger. The recovery of this energy is associated with losses so that it is uneconomical to supply this energy to the air if this can not be covered by the recovery of otherwise lost waste energy. The stimulating activity conveyed to the charge air is many times higher than the compression activity required in order to achieve the charge effect, as described e.g. in European patent application 0 126 405. For example, with air compression of 25% (pressure increase approx. 0.4 bar) the stimulating activity with the charging process is approximately 10 times as high as the compression activity.

In operating ranges with lack of air, an improvement can therefore be achieved in that the available supercharger energy is mainly converted into compression activity, and stimulating activity is largely avoided. This is possible by means of the recharging described in the aforementioned European application 01 26 405 with which towards the end of the suction stroke of the engine piston, compressed charge air is introduced into the engine cylinder. From the SAE Paper No. 8 51 523 "A NEW TYPE OF MILLER SUPERCHARGING SYSTEM FOR HIGH SPEED ENGINES" the possibility is known of concentrating the supply of compressed charge air on the start of the suction phase of the engine cylinder, which will be referred to in the following as precharging. Here, with previous charge air cooling by expansion of the air in the engine cylinder, an additional cooling effect upon the desired pressure volume can be achieved which has a positive effect upon combustion and with Diesel engines has the effect of reducing the formation of soot and the formation of NOx, and with Otto engines of reducing NOx formation and the tendency for knocking. Moreover, with both types of engine, is it optionally possible to increase power.

This invention is based, among other things, upon the knowledge that the precharging additionally offers the possibility of supplying otherwise lost energy back to the engine in the form of positive gas exchange activity.

There are different charging methods which are respectively to be considered as optimal with a given operational state, taking into account given operational requirements.

It is the object of the invention to provide an embodiment of the method specified at the start such that with all operational states of the engine a charging method corresponding to any optimization aim chosen is available which achieves a balanced optimum between e.g. the engine power, the torque, in particular with low numbers of revolutions, and fuel consumption and pollutant discharge, taking into account the respective optimization aim and maintaining reliability and the lowest possible costs, and which provides an internal combustion engine for putting the method into practice.

According to the invention the solution to this problem consists of adjusting the phasing of the air control valve with respect to the inlet valve dependent upon the desired engine operational mode between a limit position

concentrating the supply of air from the accumulator on the start of inlet and a limit position concentrating this supply of air on the end of inlet, and of blocking a line supplying uncompressed charge to each combustion chamber when there is high pressure on the side of the combustion chamber.

In this way it is possible, alongside the charging method according to the so-called charging principle, to carry out both the precharging by supplying the compressed charge air at the start of the suction phase and the recharging by supplying compressed charge air at the end of the normal suction phase.

With Diesel engines with a partial load, there is the possibility of operating the engine in the recharge range, by means of which the formation of soot is reduced due to the large supply of air, without the increase in fuel consumption associated with charging occurring.

Preferably, the opening duration of the air control valve corresponds maximally to approximately the opening duration of the inlet valve or inlet valves.

According to a further advantageous embodiment, the opening duration of the air control valve can be shortened as there is increased phase deviation between the air control valve and the inlet valve in order to facilitate concentration of the supply of air from the accumulator on the start of inlet.

In order to put the method into practice, a piston type internal combustion engine with at least one combustion chamber, which is connected to an inlet duct by means of at least one inlet valve, with a supercharger producing continuous pressure, the pressure side of which is connected to an accumulator [or storage chamber], with an air control valve between the accumulator and each inlet duct, the actuation of which is designed such that it opens and closes with the ignition frequency of the allocated combustion chambers, and with a device for changing the phasing of the inlet valve and air control valve by shifting the opening center of the air control valve from phase balance with the opening center of the respectively opening, allocated inlet valve in front of its opening center, this internal combustion engine being designed according to the invention such that the device for changing the phasing is suitable for also shifting the opening center of the air control valve behind the opening center, and that every combustion chamber can be supplied with uncompressed charge

by means of a duct which can be blocked by a valve, and bypassing a compressor branch comprising the supercharger, the accumulator and the air control valve, preferably each inlet duct (40) being connected to a duct bypassing the compressor branch.

Preferably, the device for changing the phasing consists of a computer, the inputs of which are connected to a program memory and sensors for determining operational characteristic values of the engine and/or at least one control component for issuing control commands, and the outlet of which is connected to a positioning device for the air control valve, the program memory according to a particularly advantageous embodiment containing selectable programs. In this way it is possible for the computer to select the charging method corresponding to the optimization target predetermined by the program choice and taking into account the current operational state of the engine established by the sensors, and which best corresponds to this optimization target taking into account the current control command given by the control component, e.g. the accelerator pedal of a motor vehicle.

Preferably, the sensors are disposed on the combustion chamber and/or in the accumulator and are suitable for determining the engine's operational state and pressure and temperature in the accumulator.

Preferably, the inlet side of the supercharger and the duct bypassing it are connected to one another upstream of the valve blocking this duct.

In order to provide the smoothest transition possible between the different charging methods, the phasing can be adjusted with infinite variability by the inlet valve and the air control valve.

The opening duration of the air control valve preferably corresponds maximally to the opening duration of the inlet valve, as required for conventional charging.

A very advantageous embodiment consists of a charge air cooler being disposed upstream of the air control valve, by means of which increases in power and exhaust gas improvements are possible, as already described above in connection with the concentration of the supply of air from the accumulator on the start of inlet. The advantages of the charge air cooling can also be used when the desired final pressure in the engine cylinder is the same as the

ambient pressure in the suction phase. If in such an operational state, either for reasons relating to the use or the recovery of existing supercharger actuation energy or for reasons relating to the improvement of combustion by stronger cooling, the air control valve is shut so early that the pressure in the engine cylinder falls below atmospheric pressure before reaching the bottom dead center, atmospheric air can be sucked in by means of the duct bypassing the compressor branch. This mode of operation can be advantageous with both Otto and Diesel engines in order to reduce exhaust gas emissions and fuel consumption, but also in order to increase the engine power, without loading the engine more strongly mechanically and thermally than with pure suction operation.

A particularly simple embodiment consists of the duct bypassing the compressor branch containing a directional valve which only allows flow in the direction of the inlet valve. In this way, atmospheric air is always sucked into the inlet duct when there is negative pressure here.

An operational mode can also be desirable however, with which the aforementioned concentration of the supply of air from the accumulator on the start of inlet, in the following also called precharging for short, takes place, and that then, with a closed air control valve a reduction of the pressure in the engine cylinder to below atmospheric pressure should take place in the course of the suction stroke of the engine piston, in order to bring about cooling by expansion of the charge. In order to make this type of operational mode optionally possible, it is advantageous to provide a controllable valve for the duct bypassing the compressor branch which can advantageously be blocked dependent upon the position of the air control valve.

With a particularly preferred embodiment, a valve blocking the connection to the duct bypassing the compressor branch is allocated to each inlet duct, in order to limit dead space, the valve allocated to the inlet duct and blocking the connection to the duct bypassing the compressor branch, the allocated air control valve, and the inlet valve or the inlet valves of the allocated compression chambers preferably being disposed closely adjacent to one another.

According to a further advantageous embodiment, the duct bypassing the compressor branch can contain a valve which can be actuated together with the air control valve, it being possible for both valves to also be combined in a manifold valve.

A particularly advantageous design with the embodiment with the directional valve consists of the manifold valve comprising a rotor enclosed by a valve housing, in the form of a rotation element, and continuously operated dependent upon the engine crank shaft, provided with a connection duct opening towards the housing, successive ports in the direction of circulation for the accumulator and the inlet channel being allocated to the connection duct in the valve housing.

With the embodiment with a controllable valve in the duct bypassing the compressor branch, which is combined with the air control valve to form a manifold valve, an advantageous design consists of the manifold valve comprising a rotor enclosed by a valve housing, in the form of a rotation element, and continuously driven dependent upon the rotation of the engine crank shaft, provided with a connection duct opening towards the housing, successive ports in the direction of circulation for the accumulator, the inlet duct and the duct bypassing the compressor branch being allocated to the connection duct in the valve housing, and the port for the duct bypassing the compressor branch containing a blocking component. This blocking component can preferably be in the form of a directional valve for blocking backflow.

If the air control valve only controls the admittance of compressed charge air into the inlet duct, the start of charging can be influenced by an adjustable opening edge of the connection between the accumulator and the inlet duct, and the end of charging by adjustability of the closing edge of this connection. Advantageously, the opening edge and the closing edge of this connection can be adjusted independently of one another.

With the embodiment as a manifold valve with ports for the accumulator, the inlet duct and the duct bypassing the compressor branch, it can be advantageous to design the closing edge of the connection between the duct bypassing the compressor branch and the inlet duct to be adjustable in order to

control the suction closure, and to design the opening edge of this connection to be adjustable in order to be able to influence the start of suction.

With the valve designs with a continuously circulating rotor, a further advantageous embodiment consists of the phasing of the valve opening times being adjustable with respect to the crank shaft by adjustment of the rotor relative to the valve housing.

Another advantageous embodiment using a manifold valve consists of two rotors in the form of rotational elements and continuously operated dependent upon the rotation of the engine crank shaft each being provided with a connection duct and being rotatably mounted in a valve housing, a connection duct in its open position connecting ports for the accumulator and the inlet duct, and the other connection duct in its open position connecting an inlet and an outlet for the duct bypassing the compressor branch, such that the phasing of the rotors with respect to one another can be changed and the phasing of the valve opening times with respect to the engine crank shaft can be changed by adjustment of the rotors relative to the valve housing.

Preferably, the maximum number of revolutions of the rotor or the rotors is determined such that upon two strokes of the allocated engine cylinder or allocated engine cylinders one valve opening is respectively dispensed with.

According to a particularly advantageous embodiment, the number of revolutions of the rotor or the rotors can optionally be gradually halved, by means of which there is the possibility of not charging the engine cylinder during every working cycle, but to only implement charging in intervals adapted to the power requirement.

With a four-cylinder in-line four-stroke engine a particularly simple embodiment consists of providing three inlet ducts, one inlet duct of which is allocated to the two central cylinders together. By means of this type of embodiment, a control valve, and if appropriate a separate directional valve, can be dispensed with because on the one hand, from one valve allocated to the two central cylinders together, only relatively short distances are to be covered to both cylinders, and on the other hand, the suction phases of both cylinders do not directly follow one another.

Another advantageous embodiment with a design with a directional valve in the duct bypassing the compressor branch consists of the air control valves having, for at least a number of inlet ducts of an engine, a common, tubular rotor, rotatably mounted in a tubular housing, driven dependent upon the crank shaft rotation, the internal space of which is connected to the accumulator, the inlet ducts opening out, offset to one another, on the housing in the axial direction, a valve opening being allocated to each inlet duct on the rotor, these valve openings being offset corresponding to the ignition sequence in the circumferential direction, and the phasing of the rotor being adjustable relative to the crank shaft. With this embodiment, with which preferably the admittance of compressed charge air to all of the inlet ducts of an engine is controlled by a common rotor, the inner space of the rotor is constantly connected to the accumulator, by a single port, by means of which a particularly simple arrangement is provided. The inlet ducts extending from the housing in the direction of the engine cylinders are each connected separately to the duct bypassing the compressor branch.

The advantages of the method according to the invention can also be achieved if the line for uncompressed charge does not lead into the air inlet duct leading from the supercharger to the combustion chamber, but separate inlet ducts with inlet valves on the combustion chamber, i.e. on the engine cylinder, are allocated to the compressed charge air and to the uncompressed charge air. An air stroke valve is disposed here in the inlet duct for the compressed charge, whereas a valve is disposed in the inlet duct for the uncompressed charge which closes when there is high pressure on the side of the combustion chamber such that compressed charge supplied to the combustion chamber via the other inlet channel is prevented from escaping. Due to the additional inlet valve on the engine cylinder required with separate inlet ducts, the solution described is however provided with a common inlet duct for uncompressed and compressed charge.

By means of the following description of the examples of embodiments of the invention illustrated in the drawings, this is now described in greater detail.

Fig. 1 shows a schematic illustration of a first example of an embodiment of an internal combustion engine designed according to the invention, of which only one cylinder is shown,

Fig. 2 shows a schematic illustration of another embodiment of an internal combustion engine fitted according to the invention, with the example of a four-cylinder engine,

Fig. 3 shows a schematic illustration similar to **Fig. 2** of a further embodiment of an internal combustion engine fitted according to the invention, with the example of a four-cylinder in-line engine,

Fig. 4 shows a valve arrangement with a directional valve separated from the air control valve for supplying uncompressed charge, shown schematically,

Fig. 5 shows an illustration similar to **Fig. 4** of an embodiment with which the supply of compressed and uncompressed charge is controlled by a common valve,

Fig. 6 shows a variation of the air control valve shown in **Fig. 4**,

Fig. 7 shows a variation of the air control valve shown in **Fig. 5**,

Fig. 8 shows a schematic illustration of changing the phasing of the air control valve shown in **Fig. 5** with respect to the engine crank shaft,

Fig. 9 shows a schematic axial section through another embodiment of an air control valve,

Fig. 10 shows a schematic illustration of the position of the air control valve shown in **Fig. 9** at the time of the opening of the engine inlet valve and when precharging.

Fig. 11 shows the situation at the same time when charging,

Fig. 12 shows the corresponding situation when recharging,

Fig. 13 shows a schematic axial section through a further valve arrangement for a four-cylinder engine, and

Fig. 14 shows a section according to the line XIV-XIV in **Fig. 13.**

Fig. 1 shows a cylinder 10 of a four-stroke internal combustion engine with a piston 12 which can move to and fro. The cylinder 10 has an inlet valve 14 and an outlet valve 16 to which an exhaust gas line 18 is attached. A

turbocharger 20 can be driven by the exhaust gas, and air to be compressed is supplied to said turbocharger by an air filter 22 and a line 24. The air compressed by the turbocharger 20 passes via a line 26 to an accumulator [or storage chamber] 28 which is shown here in combination with a charge air cooler 30. A line 32 leads from the accumulator 28 to an air control valve 34 which is suitable for controlling the admittance of compressed charge air from the accumulator 28 into the inlet duct 36 leading to the inlet valve 14. The inlet duct 36 is connected directly to the air line 24 leading from the air filter 22 to the supercharger 20 via a branch line 40 containing a directional valve 38, the directional valve, for example a check valve flap, being disposed such that a flow bypassing the turbocharger 20 can only take place from the air filter 22 to the inlet duct 36. So that engine operational states, in which a supply of suction air is not advantageous, can also be taken into account, the line 40 can also be fully blocked for the duration of this type of operational state, for which purpose either a separate blocking valve can be provided, or the directional valve 38 can be blocked in the blocking position.

Actuation of the air control valve 34 takes place dependent upon a computer 42 to which a program memory 44 is allocated so that there is the possibility of operating the computer 42 with a program selected from different programs held in store for the respective operational conditions. The computer 42 thus processes both automatically supplied information on the operational state of the engine, and also external control commands, as can for example be given in a motor vehicle by the positioning of the accelerator pedal. In the schematic illustration in **Fig. 1**, 46 indicates this type of accelerator pedal which is linked to the computer 42 by a connection 48. 50 indicates a sensor on the engine which is linked to the computer by a connection 56. In this way, the computer 42 can be informed not only of information on the state in the region of the engine combustion chamber, but also for example on the pressure and temperature of the stored charge air.

The computer 42 can be used in order to control the engine operational mode according to different optimization targets, and dependent upon the selection of one or another program from the program memory 44. Dependent upon the information supplied to the computer 42, the computer will thus

influence the control timings of the air control valve 34, such that the supply of compressed charge air can either be concentrated on the start of inlet of the engine cylinder 10, also referred to as precharge, or such that the compressed charge air is supplied over the whole opening duration of the inlet valve 14 of the engine cylinder 10, which corresponds to the known charging. With the embodiment shown in **Fig. 1**, the directional valve 38 is closed by the high pressure present in the inlet duct 36 when the air control valve 34 opens, such that compressed charge air is prevented from escaping. On the other hand, uncompressed air is sucked in via the directional valve 38 when the engine piston 12 with an open inlet valve 14 implements its suction stroke and the air control valve 34 is closed.

In **Fig. 2** it is shown how with a four-cylinder engine, an air control valve 34a, 34b, 34c, and 34d is respectively allocated to each of the four cylinders 10a, 10b, 10c and 10d, in this case the air control valves 34a to 34d being in the form of three-way valves, each of which has two inlets which on the one hand are connected to the line 32 for compressed air coming from the turbocharger 20, and on the other hand are connected to the line 24 for uncompressed air leading to the supercharger 20 via a respective branch line 40a to 40d, and an outlet which is respectively connected to an inlet duct 36a to 36d respectively allocated to a cylinder.

In **Fig. 2** the simplification of the illustration of the accumulators 28 with the charge air cooler 30 between the turbocharger 20 and the air control valves 34a to 34d was not shown.

Because with the ignition sequence 1-3-4-2 of a four-cylinder in-line engine the working cycles of the two central cylinders 2 and 3 do not directly follow one another, a common air control valve 34e can be allocated to them, as shown in **Fig. 3**, where in particular the distance to the two central cylinders via a common inlet duct 36e is relatively short. Branch lines 40a, 40d and 40e are connected by check valve flaps 38a, 38e and 38d. A corresponding connection of the branch lines 40a to 40d can also alternatively be chosen with the design according to **Fig. 2**. The rotor 62 of the valve 34c corresponds to the design shown in **Fig. 7** with two sections 64 and 65.

The embodiment according to **Fig. 3** shows a closely adjacent arrangement of the engine inlet valves 14a and 14d and of the group of inlet valves 14b and 14c with respect to the allocated air control valves 34a, 34d and 34e and the check valve flaps 38a, 38d and 38e, by means of which the dead spaces allocated to the individual engine cylinders can be reduced to a minimum and the accuracy with which the gas exchange can be controlled is improved.

The design shown in **Fig. 1** with a directional [control] valve 38 in a branch line 40 leading directly out into the inlet duct 36 is shown in a somewhat different representation in **Fig. 4**, the function of the air control valve 34 being described in greater detail below. In order to simplify the illustration, the accumulator 28 with the air charge cooler 30 is also left out here between the supercharger 20 and the air control valve 34. With sufficient line volume, the line connection between the supercharger 20 and the air control valve 34 could also serve here as an accumulator.

The air control valve shown in **Fig. 4** has a valve housing 60 in which a rotor 62 circulates, continuously operated dependent upon the rotation of the engine crank shaft. This rotor 62 is in the form of a rotational element and has a sector-like section 64 which with a suitable angular position of the rotor 62 allows a flow between the inlet slit 66 and the outlet slit 68. As can clearly be seen in **Fig. 4**, the connection between the inlet slit 66 and the outlet slit 68 is maintained, while the rotor 62 rotates by approximately 90°. If the rotor 62 is operated with half the number of revolutions of the engine crank shaft, this 90° corresponds to a crank shaft rotation of 180°. With corresponding phasing of the rotor 62 with respect to the engine crank shaft, the connection between the inlet duct 36 and the air compressed by the supercharger 20 during a full suction stroke of the engine piston can be maintained as is required for conventional charging. If the phasing of the rotor 62 is changed with respect to the engine crank shaft with respect to the phasing allocated to the charging such that the rotor 62 runs ahead of the crank shaft, for example such that the opening center of the air control valve 34 coincides with the start of opening of the inlet valve 14, the so-called precharging is brought about with which the supply of air from the supercharger 20 is concentrated on the start of inlet of the

inlet valve 14. The air control valve breaks the connection of the inlet duct 36 with the compressed charge air from the supercharger 20 a fairly long time before closure of the inlet valve 14, for example approximately in the middle of the suction stroke of the piston 12. With the design according to **Figs. 1** and **4**, the negative pressure then present in the inlet duct 36 will open the directional valve 38 so that uncompressed air is taken in via the branch line 40 into the inlet duct 36 and through the inlet valve 14 into the engine cylinder 10 until the inlet valve 14 closes.

If the phasing of the rotor 62 is changed with respect to the crank shaft in the opposite direction, the connection between the compressed charge air and the inlet duct 36 via the air control valve 34 will only open some time after the opening of the inlet valve 14 so that the piston 12 first of all takes in uncompressed air via the directional valve 38 before the air control valve 34 opens towards the end of the suction stroke of the piston 12, and in addition to the air previously taken in, compressed air from the supercharger flows into the cylinder 10. For example, the phase displacement can be chosen to be so great that the air control valve 34 only opens a short time before closure of the inlet valve 14 so that even with a relatively large supercharger output, as is to be expected in the range of low numbers of revolutions, the supercharger energy can be converted into compression activity.

With the design according to **Figs. 1** and **4**, air is constantly sucked in via the branch line 40 if the inlet valve 14 is open and the air control valve 34 is closed. In the event of precharging, it may however be desirable to prevent external air being sucked in via the branch line 40 after closure of the air control valve 34 in order to cool down the compressed air coming from the supercharger and present in the engine cylinder 10 by expansion. This can for example happen in that with the arrangement shown in **Fig. 4**, a block valve is disposed in the branch line 40 which in this operational mode is closed.

Fig. 5 shows a variation with which the branch line 40 is not directly connected into the inlet duct 36, but onto the valve housing 60 by means of a slit 70, and the opening and closing of the branch line 40 is in this way controlled by the rotor 62. The directional [control] valve 38 in the branch line 40 is eliminated with this design. As one can see from **Fig. 5**, the opening

phase of the branch line 40 with respect to the inlet duct 36 is respectively directly after the opening phase for the charge air compressed by the supercharger 20. In the event of charging, during the opening phase of the branch line 40, the inlet valve 14 on the engine is closed again so that only compressed air passes into the cylinder 10. In the event of precharging, the connection between the branch line 40 and the inlet duct 36 remains closed when the air control valve 34 has broken the connection serving to supply compressed charge air between the slit 66 and the slit 68. With this embodiment, the precharging can only be implemented in connection with the expansion cooling.

Fig. 6 shows a variation of the air control valve shown in **Fig. 4** which only has the two ports 66 for the compressed charge air in the direction going towards the inlet duct 36. With this variation, inside the valve housing 60 there is an outer aperture ring 100 disposed concentrically to the valve housing 60 and an inner aperture ring 102. In both aperture rings 100 and 102 windows 104 and 106 are allocated to the slit 66 in the housing 60, and windows 108 and 110 allocated to the slit 68. Both aperture rings 100 and 102 can be adjusted both independently of one another and respectively together with one another in the same direction of movement, as suggested schematically by the positioning components 112 and 116. The positioning component 112 of the outer aperture ring 100 is guided outwards by a slit 114 in the valve housing 60. The positioning component 116 on the inner aperture ring 102 passes through a slit 118 on the outer aperture ring 100 and a slit 120 in the valve housing 60.

The windows 108 and 110 extend over a sufficiently large angle so that in any position of the aperture rings 100 and 102, the edge lying opposite the direction of rotation of the rotor of the slit 68 leading to the inlet duct 36 is kept open. Moreover, the edge lying in the direction of rotation of the rotor of the window 110 is also disposed such that it also always keeps the slit 68 open. The edges of the window 108 serving as a closing edge 123 lying in the direction of rotation of the rotor 62, and the edges 122 of the window 106 serving as an opening edge in the inner aperture ring 102 lying opposite the direction of rotation of the rotor allow adjustment of the operation mode between precharging, charging and recharging. If the closing edge 123 is moved into the

region of the slit 68, the air control valve 34 closes in front of the engine inlet valve 14 which corresponds to precharging. If the opening edge 122 moves into the region of the slit 66, the air control valve 34 opens later, which corresponds to recharging. The edges of the windows 104 and 106 lying in the direction of rotation of the rotor are disposed such that they do not influence the opening cross-section of the slit 66. One could also dispose the opening edge 122 and the closing edge 123 on a single aperture ring and adjust them respectively together, double the adjustment space then being necessary however for this single aperture ring. The movement of the rotor 62n is either brought about by direct actuation of the engine crank shaft or by actuation of the engine cam shaft.

Fig. 7 shows a variation of the air control valve 34 shown in **Fig. 5**, with which the branch line 40 is also connected to the air control valve 34. The opening edge 72 of the slit 66, the opening edge 74 of the slit 68, and the closing edge 76 of the slit 70 can be adjusted here by slide valves 78, 80 and 82 which can be moved independently of one another, for which the slide valves are provided with positioning components 84, 86 and 88. By means of the slide valve 78, the start of charging, by means of slide valve 80 the start of suction, and by means of slide valve 82 the end of suction from the branch line 40 can be changed.

Unlike the illustration in **Fig. 5,** in **Fig. 7** the rotor 62 is also provided with a second cut-out 65. As soon as the rotor has broken the connection between the slit 70 and the slit 68 by corresponding rotation of the rotor 62, the cut-out 65 reaches the region of the slit 68 and connects this to the slit 70. Only with phasing of the rotor 62 with respect to the engine crank shaft corresponding to the precharging is the inlet valve 14 of the engine open at this time so that following the introduction of compressed charge air into the cylinder 10 at the start of the suction stroke of the piston 12, air which is still uncompressed can be taken in from the branch line 40. If in such a case expansion cooling of the compressed charge air introduced into the engine cylinder 10 by precharging is desired, the branch line 40 can be closed by a blocking valve 39 disposed on it.

Fig. 8 only shows as an example how the phasing of the opening phases of the air control valve 34 can be changed with respect to the crank shaft

position of the engine. With the arrangement shown in **Fig. 8,** a position member 94, the length of which can be changed for example hydraulically, is used for this purpose which on the one hand with 96 engages onto a lever 90 actuated dependent upon the engine crank shaft and mounted concentrically to the rotor 62 and on the other hand onto the rotor 62 so that the angular position of the rotor 62 with respect to the lever 90 can be changed. Basically however, there is also the possibility of not adjusting the rotor 62, but of adjusting the valve housing 60 with respect to the rotor 62.

Figs. 9 to **12** show a further variation of the air control valve 34. With this design, two rotors 130 and 132 are disposed coaxially to one another within the valve housing 138, the port 66 leading to the accumulator 28 and a branch 68a of an port 68 leading to the inlet duct 36 being allocated to the in **Fig. 9** upper rotor 130 in the housing 138. An port 70 connected to the branch line 40 and a further branch 68b of the port 68 leading to the inlet duct 36 is allocated to the lower rotor 132 in **Fig. 9.** The rotor 130 is provided with a connection duct 134, and the rotor 132 with a connection duct 136. For better understanding, in **Fig. 9** the ports 66 and 70 on the one hand , and the port 68 on the other hand are shown as being offset 180° from each other, whereas, as shown by **Figs. 10** to **12,** these ports are actually offset to one another by approximately 90°. Also for simplification of the illustration, in **Figs. 10** to **12** both rotors 130 and 132 are not disposed coaxially, but are shown purely schematically, offset to one another on the side.

The valve housing 138 is crossed by a drive shaft 140 actuated dependent upon the rotation of the engine crank shaft, and which is enclosed by a hollow shaft 142 connected to the rotor 132, on which in turn a hollow shaft 144 connected to the rotor 130 is disposed such that it can make rotational movements.

In **Fig. 9,** both the drive shaft 140 and the hollow shafts 142 and 144 are guided out of the valve housing 138 towards the upper side, and there are provided with radially extending levers 146, 148 and 150, it being possible for both the lever 148 and the lever 150 to be adjusted independently of one another with respect to the lever 146 by adjustment components (not shown), in order to change the phasing of the rotors 130 and 132 independently of one

another. The arrangement can however also be made such that the lever 148 can be adjusted with respect to the lever 146 and the lever 150 with respect to the lever 148, independent phase adjustment of the two rotors 130 and 132 also being made possible by corresponding control of the positioning components disposed between the levers. Moreover, the arrangement is made such that as well as the change of the phasing of the two rotors 130 and 132 independently of one another with respect to the drive shaft 140, a combined change of the phasing of both rotors 130 and 132 with respect to the drive shaft 140 is also possible.

In **Fig. 10**, the position of both rotors 130 and 132 at the start of the engine suction stroke at the so-called precharging is shown. It is assumed that the drive shaft 140 circulates with half the number of revolutions of the crank shaft. The connection duct 134 extends over a sector of approximately 105° so that in the event of the so-called charging, compressed charge air from the accumulator 28 can be supplied to the engine cylinder during the whole suction stroke.

When the engine inlet valve 14 opens, as shown in **Fig. 10**, the opening edge of the connection duct 134 has already moved out so far over the port 68a that the connection between the port 66 and the port branch 68a is broken after a further rotation of the drive shaft 140 by approximately 50° if the engine piston 12 has run through a little more than half of the suction stroke. Whereas compressed charge air can flow via the connection duct 134 and the inlet duct 36 through the inlet valve 14 and the cylinder 10, the connection between the port 70 and the port branch 68b is closed. With the angular position between the rotor 130 and the rotor 132 shown in **Fig. 10**, this connection opens as soon as the connection between the port 66 and the port branch 68a closes so that following precharging, uncompressed charge air can flow into the engine cylinder 10 until the inlet valve 14 closes. It can also be seen in **Fig. 10** however that the rotor 132 can be adjusted with respect to the position shown here in the opposite direction to circulation so far that on the one hand, when the inlet valve 14 is opened, it has already broken the connection between the port 70 and the branch 68b, and that on the other hand, it keeps this connection

broken, even during the whole opening duration of the inlet valve 14 so that precharging is even possible without subsequent intake of uncompressed air.

In **Fig. 11** the drive shaft 140 adopts the same angular position as in **Fig. 10** after here too the time has been reached when the inlet valve 14 opens. The rotor 130 is adjusted with respect to the drive shaft 140 in the direction opposite to circulation such that it now releases the connection between the port 66 and the port branch 68a. The angular position of the rotor 132 with respect to the rotor 130 is also changed so that the connection between the port 70 and the port branch 68b remains broken for as long as the inlet valve 14 is open. The supply of compressed charge air to the so-called charging therefore takes place over the whole suction stroke of the piston 12.

In **Fig. 12** the rotor is adjusted still further with respect to the drive shaft 140 in the direction opposite circulation, the rotor 132 having taken part in this position movement without changing its position with respect to the rotor 130. Because the situation when opening the inlet valve 14 is shown again, one can see that the connection between the port 70 and the port branch 68b is already open, whereas the connection between the port 66 and the port branch 68a is still broken. The piston 12 therefore first of all takes in uncompressed air. The two rotors 130 and 132 adopt an angular position with respect to one another such that the connection 70 is blocked when the port 66 is opened for so-called recharging following a rotation of the drive shaft 140 by approximately 75 degrees, i.e. bringing the piston 12 towards the bottom dead center.

Any intermediary positions can be set at any time.

With the embodiment shown in **Figs. 13** and **14**, the starting point is the non-limiting notion of the situation with a four-cylinder in-line engine, an inlet duct 36a, 36b, 36c and 36d being allocated to each engine inlet valve. The duct 40 bypassing the compressor branch 20, 28, 34 (**Fig. 1**) is respectively connected by a check valve flap 38 to each of the inlet ducts 36a to 36d. In the way already described, an air control valve 34a to 34d is allocated to each of the inlet ducts 36a to 36d in order to make it possible for the compressed charge air from the accumulator 28 to be admitted to the individual engine cylinders corresponding to the ignition sequence and the chosen phasing. With the embodiment shown in **Figs. 13** and **14,** these air control valves 34a to 34d

are combined to form a common subassembly with a common rotor 62f which is tubular in form and rotatably mounted in a common housing 60f. The rotor 62f is actuated dependent upon the crank shaft rotation, its phasing with respect to the crank shaft being changeable, however, by means not shown in detail here. The individual inlet ducts 36a to 36d are attached to the housing 60f in the axial direction, offset to one another. In the corresponding axial position are located the valve openings 64a to 64d allocated to the inlet ducts 36a to 36d in the rotor, which are offset in the circumferential direction of the rotor 62f corresponding to the ignition sequence of the engine cylinder. The devices for actuating the rotor 62f and for adjusting its phasing, and the connection of the internal space 160 to the accumulator 28 can be implemented in any way which does not pose any difficulty for an expert in the field, and so are therefore not described in greater detail here.

With the example shown, it is assumed that the rotor 62f is actuated with half the number of revolutions of the crank shaft so that the rotor 62f will implement a full rotation, whereas for example on a four-cylinder in-line engine, the ignition sequence 1-3-4-2 will be run through once. The valve openings 64a, 64c, 64d and 64b pass through a corresponding sequence so as to coincide with the ports of the inlet ducts 36a, 36c, 36d and 36b.

If one reduces the number of revolutions of the rotors 62 or 130 and 132 to a quarter of the number of revolutions of the crank shaft, each combustion chamber will only be supplied with charge air in every second working cycle so that with a low power requirement with a constant number or revolutions of the engine, the individual working cycle will run with higher cylinder charging and so with more favourable specific fuel consumption. By further reducing the power requirement, the number of revolutions of the rotors can be halved again.

In order to simplify the illustration, in the preceding description one spoke of compressed or uncompressed air. This can however also be charge air mixed with fuel – as is obvious to an expert in the field.

Patent Claims

1. A method for operating a piston-type internal combustion engine, in particular a reciprocating piston engine, with which each combustion chamber is connected to an inlet duct by means of at least one inlet valve controlled dependent upon the piston movement, with a supercharger producing a continuous pressure and supplying an accumulator [or storage chamber], and an air control valve disposed between the accumulator and each inlet duct, said air control valve opening and closing dependent upon the ignition frequency of the allocated combustion chambers, it being possible to shift the phasing of the opening center of the air control valve from phase balance with the opening center of the respectively opening, allocated inlet valve in front of its opening center, **characterized in that** the phasing of the air control valve with respect to the inlet valve is adjusted dependent upon the desired engine operational mode between a limit position concentrating the supply of air from the accumulator on the start of inlet and a limit position concentrating this supply of air on the end of inlet, and that a line supplying each combustion chamber with uncompressed charge is blocked when there is high pressure on the side of the combustion chamber to be supplied.

2. The method according to Claim 1, characterized in that the opening duration of the air control valve corresponds maximally to approximately the opening duration of the inlet valve or the inlet valves of each combustion chamber.

3. The method according to either of Claims 1 or 2, characterized in that the opening duration of the air control valve is shortened between the air control valve and the inlet valve as the phase deviation increases.

4. An piston-type internal combustion engine, in particular a reciprocating piston engine, for putting the method according to Claim 1 into practice, with at least one combustion chamber (10) which is connected to an inlet duct (36) by at least one inlet valve (14), with a supercharger (20) producing a continuous pressure, the pressure side of which is connected to an accumulator (34), with an air control valve (34) between the accumulator (28) and each inlet duct (36), the actuation of which is designed such that it opens

and closes dependent upon the ignition frequency of the allocated combustion chambers (10), and with a device (42) for changing the phasing of the inlet valve (14) and the air control valve (34) by displacing the opening center of the respectively opening, allocated inlet valve (14) to before its opening center, characterized in that the device (42) for changing the phasing is suitable for also shifting the opening center of the air control valve (34) to behind the opening center of the respectively opening allocated inlet valve (14) and that each combustion chamber (10) can be supplied with uncompressed charge via a duct (40) which can be blocked by a valve (38) and bypassing the compressor branch comprising the supercharger (20), the accumulator (28) and the air control valve (34).

5. The internal combustion engine according to Claim 4, characterized in that each inlet duct (36) is connected to the duct (40) bypassing the compressor branch.

6. The internal combustion engine according to either of Claims 4 or 5, characterized in that the device for changing the phasing consists of a computer (42), the inlets (48, 52, 56) of which are connected to a program memory (44) and sensors (50, 54) for determining operational characteristic values of the engine and/or at least one control component (46) for issuing control commands, and the outlet of which is connected to a positioning device for the air control valve (34).

7. The internal combustion engine according to Claim 6, characterized in that the program memory contains selectable programs.

8. The internal combustion engine according to Claim 6, characterized in that the sensors (50, 54) are disposed on the combustion chamber (10) and/or on the accumulator (28), and are suitable for determining the engine operational state and the pressure and temperature in the accumulator (28).

9. The internal combustion engine according to Claim 6, characterized in that the control component is an accelerator pedal (46) of a motor vehicle.

10. The internal combustion engine according to either of Claims 4 or 5, characterized in that the inlet side (24) of the supercharger (20) and the duct

(40) bypassing the latter upstream of the valve blocking this duct (40) are connected to one another.

11. The internal combustion engine according to either of Claims 4 or 5, characterized in that the phasing of the inlet valve (14) and the air control valve (34) is infinitely adjustable.

12. The internal combustion engine according to either of Claims 4 or 5, characterized in that the opening duration of the air control valve (34) corresponds maximally to the opening duration of the air inlet valve (14).

13. The internal combustion engine according to any of Claims 4, 5 or 12, characterized in that the opening duration of the air control valve (34) is adjustable.

14. The internal combustion engine according to any of Claims 4 to 13, characterized in that a charge air cooler (30) is disposed upstream of the air control valve (34).

15. The internal combustion engine according to any of Claims 4 to 14, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) contains a directional valve (38) which only allows flow in the direction of the inlet valve (14).

16. The internal combustion engine according to any of Claims 4 to 14, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) can be blocked dependent upon the position of the air control valve (34).

17. The internal combustion engine according to Claim 5, characterized in that a valve (38) blocking the connection to the duct (40) bypassing the compressor branch (20, 28, 34) is allocated to each inlet duct (36).

18. The internal combustion engine according to Claim 17, characterized in that the valve (38a, 38d, 38e) blocking the connection to the duct (40a, 40d, 40e) bypassing the compressor branch (20, 28, 34) allocated to the inlet channel (36a, 36d, 36e), the allocated air control valve (34a, 34d, 34e), and the inlet valve or the inlet valves (14a, 14d, 14b, 14c) of the allocated combustion chambers (10a, 10d, 10b, 10c) are disposed closely adjacent to one another.

19. The internal combustion chamber according to any of Claims 16 to 20, characterized in that the duct (40) bypassing the compressor branch (20, 28, 34) contains a valve (62, 70) which can be operated together with the air control valve (62, 66).

20. The internal combustion chamber according to any of Claims 16 to 18, characterized in that the valve (62, 70) in the duct (40) bypassing the compressor branch (20, 28, 34) and the air control valve (62, 66) are combined in a manifold valve.

21. The internal combustion chamber according to Claims 5 and 20, characterized in that the manifold valve is a three-way valve, the ports (66, 68, 70) of which are connected to the accumulator (28), the inlet duct (36) and the duct (40) bypassing the compressor branch (20, 28, 34).

22. The internal combustion engine according to any of Claims 4 to 15, characterized in that the air control valve comprises a rotor (62) enclosed by a valve housing (60), in the form of a rotational element, and continuously operated dependent upon the rotation of the engine crank shaft, provided with a connection duct (64) opening towards the housing, successive ports (66, 68) in the direction of circulation for the accumulator (28) and the inlet duct (36) being allocated to the connection duct (64) in the valve housing (60).

23. The internal combustion engine according to Claims 5 and 21, characterized in that the manifold valve comprises a rotor (62) enclosed by a valve housing (60), in the form of a rotational element, and continuously operated dependent upon the rotation of the engine crank shaft, provided with a connection duct (64) opening towards the housing, successive ports (66, 68, 70) in the direction of circulation for the accumulator (28), the inlet duct (36) and the duct (40) bypassing the compressor branch (20, 28, 34) being allocating to the connection duct (64) in the valve housing, and the port for the duct (40) bypassing the compressor branch containing a blocking component.

24. The internal combustion engine according to Claim 27, characterized in that the blocking component is a directional valve for blocking a back flow.

25. The internal combustion engine according to either of Claims 20 or 21, characterized in that the opening edge (72, 122) of the connection (66, 64, 68) between the accumulator (28) and the inlet duct (36) is adjustable.

26. The internal combustion engine according to any of Claims 22 to 24, characterized in that the closing edge (123) of the connection (66, 64, 68) between the accumulator (28) and the inlet duct (36) is adjustable.

27. The internal combustion engine according to Claim 26, characterized in that the opening edge (122) and the closing edge (123) of the connection (66, 64, 68) between the accumulator (28) and the inlet duct (26) are adjustable independently of one another.

28. The internal combustion engine according to either of Claims 23 or 24, characterized in that the closing edge (76) of the connection (70, 64, 68) between the duct (40) bypassing the compressor branch (20, 28, 34) and the inlet duct is adjustable.

29. The internal combustion engine according to either of Claims 23 or 24, characterized in that the opening edge (74) of the connection (70, 64, 68) between the duct (40) bypassing the compressor branch (20, 28, 34) and the inlet duct (36) is adjustable.

30. The internal combustion engine according to any of Claims 22 to 28, characterized in that the phasing of the valve opening times with respect to the crank shaft is changeable by adjusting the rotor (62) relative to the valve housing (60).

31. The internal combustion engine according to Claim 20, characterized in that two rotors (130, 132) in the form of rotation elements and continuously operated dependent upon the rotation of the engine crank shaft are each provided with a connection duct (134, 136) and rotatably mounted in a valve housing (138), a connection duct (134) in its open position connecting ports (140, 142) for the accumulator (28) and the inlet duct (36), and the other connection duct (136) in its open position connecting an inlet (144) and an outlet (146) for the duct (40) bypassing the compressor branch (20, 28, 34), such that the phasing of the rotors (130, 142) with respect to one another is changeable, and that the phasing of the valve opening times with respect to the

engine crank shaft is changeable by adjusting the rotors (130, 132) relative to the valve housing (138).

32. The internal combustion engine according to any of Claims 21 to 31, characterized in that the maximum number of revolutions of the rotor (62, 130, 132) is determined such that upon two strokes of the allocated engine cylinder or the allocated engine cylinders, one valve opening is respectively dispensed with.

33. The internal combustion engine according to Claim 32, characterized in that the number of revolutions of the rotor (62, 130, 132) can optionally be gradually halved.

34. The internal combustion engine according to any of Claims 4 to 33, characterized in that with a four-cylinder in-line four-stroke engine, three inlet ducts (36a, 36b, 36c) are provided, of which one inlet duct (36b) is allocated to the two central cylinders together.

35. The internal combustion engine according to Claim 15, characterized in that the air control valves (34a, 34b, 34c, 34d) of at least a number of inlet ducts (36a, 36b, 36c, 36d) of an engine have a common, tubular rotor, rotatably mounted in a tubular housing (60f), operated dependent upon the crank shaft rotation, the internal space (160) of which is connected to the accumulator (28), such that the inlet ducts (36a,, 36b, 36c, 36d) lead out on the housing (60f), offset to one another in the axial direction, such that a valve opening (64a, 64b, 64c, 64d) is allocated to each inlet valve (36a – 36d) on the rotor (62f), these openings (64a-64d) being offset in the circumferential direction corresponding to the ignition sequence, and that the phasing of the rotor (62f) relative to the crank shaft is adjustable.